

Low-temperature NPP Spent Fuel Reactor

Field of technology

This invention relates to nuclear reactor technology, specifically to a low-temperature nuclear reactor using NPP spent fuel as its nuclear fuel.

Background of the Invention

Nuclear power plant (NPP) spent fuel is a fuel, which reaches expected burn-up but is below its limit but can't meet the requirements of NPP operation and hence is discharged.

Generally, about 0.9-1.1% U-235 remains in the spent fuel assembly discharged from a nuclear power plant and some fissile materials such as 0.6% of Pu-239 and 15% of Pu-241 etc. are newly generated. They are usable resources.

At present, two kinds of basic policies are adopted for NPP spent fuel management in the world. One is the "once-through" fuel cycle, whereby NPP spent fuel is directly disposed of after interim storage without reprocessing. The second is spent fuel reprocessing, whereby the remaining U-235 and the generated Pu-239 in spent fuel are extracted through reprocessing and fabricated into mixed oxide fuel (MOX) to be reused as NPP fuel. Obviously, usable uranium is not utilized completely in the "once-through" fuel cycle. Although uranium utilization is improved by reusing the remaining U-235 and newly generated Pu-239 through reprocessing as NPP fuel, the reprocessing cost for spent fuel is quite high.

In order to make full use of these resources, Canada, South Korea and US are working together to develop a new technology, whereby the PWR spent fuel core pellets are reprocessed and fabricated into Canadian Deuterium-Uranium Reactor (CANDU) fuel elements for continual use in heavy water reactor nuclear power plant (PHWR NPP). That

is "Directly using Pressurized Water Reactor into CANDU ("DUPTC") project, in which technology is very complicated, with high cost and under development.

In addition, the utilization of decay heat and gamma from spent fuel is considered.

NPP operation practices and fuel assembly irradiation tests have showed that spent fuel doesn't reach its burn-up limit. Therefore spent fuel can be directly used as long as spent fuel assemblies are properly examined and evaluated. This invention uses spent fuel to make core with low parameters heating reactor and thereby to utilize its fission energy.

The low-temperature reactor is a kind of reactor, the core of which consists of fuel assemblies, normal temperature and pressure coolant and moderator. Fission-generated heat is taken out of the core by the normal temperature and pressure coolant flowing through the fuel assemblies, low-temperature hot water is supplied to customers through a heat exchanger, and water layer mainly used as neutron moderation and radiation shield. The core is made up of the fuel assemblies, the upper and lower core grid plates, and the control rods and their drive mechanisms. The fuel assemblies are fixed with the upper and lower core grid plates. The control rods are inserted from the top of the core into a lattice made up of the upper and lower core grid plates and the fuel assemblies. The upper end of the control rod is connected with its drive mechanism. The core is located in the core pool, where there are coolant inlet and outlet nozzles, which are connected with a heat exchanger through pipes. The core heat is carried out through coolant to supply hot water without any radioactivity to the heat network.

The low-temperature reactors that have been designed and constructed in the world can be divided into two types. One is the metal containment pressurized reactor, featured by the natural circulation boiling water reactor designed and constructed by West

Germany and Russia, the core of which is located in the pressure-resistant vessel and the in-core structure is alike to the power reactor. The other is pressure bearing pre-stressed concrete containment reactor, for example the low-pressure pressurized water reactor designed by Sweden. There are also two kinds of low-temperature reactors in China, i.e. pressure vessel and pool types. In all the low-temperature reactors at home and abroad, unirradiated nuclear fuel is used.

Nuclear heat supply is an important means for heating and desalination. Though many design concepts of low-temperature heat supply reactor exist at home and abroad, they have not been widely accepted because of their economics and safety. So low construction cost and reliable safety are decisive factors in promoting nuclear heat supply reactor. This invention can properly ensure the economics and safety of low-temperature heating reactor.

Summary of the Invention

This invention is aimed at supplying a low-temperature and low-pressure reactor, which directly uses NPP spent fuel for desalination, heat supply and isotope production, and features low construction cost, safety and reliability.

The invention claimed is a low-temperature NPP spent fuel reactor, wherein a core of the reactor is made up of spent fuel assemblies, upper and lower core grid plates, control rods and drive mechanisms thereof. The fuel assemblies are fixed with the upper and lower core grid plates. Each of the control rods is inserted from the top of the core into a lattice made up of upper and lower core grid plates and the fuel assemblies. The upper end of the control rod is connected with its drive mechanism. The core is located in a core vessel located under a core pool, which core pool is provided with coolant inlet and outlet nozzles, which are connected with a heat exchanger through pipes. NPP spent fuel is

directly used as nuclear fuel and light water is used as coolant and moderator in the reactor. A sealing cover, on the top of the core pool, is filled with a pressurized gas to constitute a pressurized air cavity forming a primary air shield. Additionally, on the top of the core pool there is provided an airtight shield to form a secondary air shield. A pressurizer or a large pool is connected with the coolant inlet nozzle to improve the static pressure and maintain the pressure at a core outlet. Within the core pool there is an underwater handling canal, which is connected with a spent fuel storage pond and an additional schema of reloading water layer is replaced by the under water handling canal. A residual heat cooler is provided in the spent fuel storage pond and an electromagnetic valve is arranged at a connection tube connecting the core vessel with the residual heat cooler to constitute a passive residual heat removal system.

In the low-temperature and low-pressure reactor, NPP spent fuel is directly used as nuclear fuel. The core can not only reach criticality, but also has much backup reactivity to meet operation requirements. The backup reactivity mainly stems from:

1. The temperature reduction can produce positive reactivity, when NPP high parameters are changed into low parameters;
2. The equilibrium xenon toxicity absorption reactivity reduction can also produce positive reactivity, when power density is reduced (neutron flux reduction);
3. Appropriate moderate reflector is added around the core as necessary to reduce neutron leakage and increase backup reactivity;
4. Because of the slag existing in the core consisting of the spent fuel, Sm-149 and Sm-151 absorb neutron de-poisoning and produce positive reactivity during operation to extend operation lifetime.

Core loading nuclear designs as well as thermal calculation show that the low-temperature and low-pressure reactor of NPP spent fuel has the following safety features:

1. Temperature coefficient is negative value under condition from cold state to hot state.
2. The volume of assembled core is large and power density is low, only 1/12-1/15 of the power density of the nuclear power plant. The highest temperature of fuel matrix is only 400°C at nominal power. Together with inherent safety and passive safety features of the reactor, the core will not be melted down in case of severe accidents.
3. Because more than one airtight is used to prevent radioactive gases from being released into the atmosphere and the radioactive gases are treated effectively, the requirement of “no radiological consequence” to the environment specified by regulations is satisfied.

The effects of the invention disclosed herein are as follows:

1. The neutron chain reaction device that reuses the spent fuel from the nuclear power plant as nuclear fuel promotes the utilization of uranium without any new spent fuel production. The fuel assemblies discharged from the nuclear power plant can be loaded into the reactor followed by proper inspection. Therefore, the costs of fuel as well as the investment costs and reactor operation costs are significantly reduced, economic and environmental impact are reduced.
2. Because of low power density and passive residual heat removal, the core will not be melt down in case of severe accidents. With provision of at least one airtight shield and satisfaction with requirement of “no radiological consequence”, this reactor is of high inherent safety and good safety performance.

3. Because the NPP spent fuel core has much backup reactivity and fully satisfies the requirements for nuclear heat supply, the heat energy produced can be used for desalination, central district heating and non-carrier radioisotope production.
4. A special underwater fuel handling canal is used to replace a conventional fuel handling system. The simplified handling process and equipment facilitate operation and enhance safety.

Brief Description of the Drawings

Figure 1 The Schematic Diagram of the first example of the Low-temperature NPP Spent Fuel Reactor (Pressurizer Pressurization)

Figure 2 The Schematic Diagram of the second example of the Low-temperature NPP Spent Fuel Reactor (Air Cavity Pressurization)

In the figures:

Reference numeral 1 denotes a support skirt; reference numeral 2 identifies a lower core grid plate; reference numeral 3 identifies the fuel assembly; reference numeral 4. identifies the core vessel; reference numeral 5. identifies the upper core grid plate; reference numeral 6. identifies a control rod and its drive mechanism; reference numeral 7. identifies a concrete biological shield; reference numeral 8. identifies the core pool; reference numeral 9. identifies a coolant inlet nozzle; reference numeral 10. identifies a coolant outlet nozzle; reference numeral 11. identifies a sealing cover; reference numeral 12. identifies a secondary airtight shield; reference numeral 13. identifies a pressurizer; reference numeral 14. identifies a handling canal; reference numeral 15. identifies a spent fuel storage pond; reference numeral 16. identifies a handling carriage; reference

numeral 17. identifies a pressurized air cavity; reference numeral 18. identifies an electro-magnetic valve and reference numeral 19. identifies a residual heat cooler.

Detailed Description of the Preferred Embodiments

Example 1

By way of example, this invention uses a 200MW(t) heating supply reactor, as shown in Figure 1. A concrete biological shield (7) is used to enclose a core pool (8) and a spent fuel storage pond (15). Coolant inlet and outlet nozzles (9, 10) are set on an upper part of the core pool (8). On the side of the core pool (8) there is provided an underwater handling canal (14), which is connected with the spent fuel storage pool (15) and is plugged with a sealing plug when the reactor is in operation to ensure the core pond (8) is isolated from the spent fuel storage pond 15. Spent fuel shipping casks and the fuel storage racks may be located in the spent fuel storage pond (15), with a handling carriage (16). The canal (14) is open in case of handling to transport the spent fuel assemblies. The concrete biological shield (7) is covered with a layer of stainless steel to prevent the pool from leaking. The core vessel (4) is located under the core pool (8). The core is made up of the fuel assemblies (3), upper and lower core grid plates (5,2), control rods and their drive mechanisms (6). The fuel assemblies (3) are fixed with the upper and lower core grid plates (5,2). The control rod is inserted from the top of the core into a lattice (5, 2, 3) made up of the upper and lower core grid plates (5,2) and fuel assemblies (3). The upper end of the control rod is connected with its drive mechanism. The core is located in the core vessel (4) under the core pool (8). The fuel assemblies are the spent fuel assemblies discharged from nuclear power plant, and are arranged in the core according to the burn-up of different groups of spent fuel assemblies. When backup reactivity is needed, the spent fuel assembly with deep burn-up is arranged in the center of the core and the spent

fuel assembly with light burn-up in the periphery of the core. A graphite reflector is arranged around the core as necessary to reduce neutron leakage and improve backup reactivity. When radial power distribution needs to be flattened out, the spent fuel assemblies are arranged in reverse. The fuel assemblies of the core are inserted in the lower core grid plate (2) and are pressed and fixed by the upper core grid plate (5) to prevent the fuel assemblies from moving up and down. The lower end of the core is supported by a support skirt (1).

There are two kinds of core configurations. Figure 1 shows a type of pressurizer under static pressure. The coolant inlet nozzle (9) is connected with a pressurizer (13), which is located on higher position to form core outlet pressure. The core vessel (4) under the core pool (8) is completely filled with water. The core vessel (4) and the coolant circuit constitute a primary boundary to prevent radioactive water from spilling. The drive mechanism is fixed on a sealing cover (11) located on the top of the core pool and connected with the control rod. At the top of the core pool (8) there is provided an airtight shield (12). The area between the sealing cover (11) of the core pool (8) and the airtight shield (12) is at a negative pressure and thus constitutes an airtight shield to prevent radioactive gases from being released into the environment. A residual heat cooler (19) is located in the spent fuel storage pond (15). An electromagnetic valve (18) is arranged at a connection tube connecting the core vessel with the residual heat cooler. In case of external power supply loss, the electromagnetic valve (18) is automatically de-energized and opens. Hot water flows through tubes of the residual heat cooler (19) and is cooled by the water from the spent fuel storage pond (15) constituting dual natural circulation and heat exchange. The spent fuel storage pond is a final heat sink. When temperature is too high, the heat is carried away by water evaporation.

Example 2

Unlike Example 1, Example 2 is another configuration of the core where the core pool is filled with air. The atmosphere is used to form pressure at the core outlet, as shown in Figure 2. A sealing cover (11) like a cap is located on the top of the core pool (8) to form a pressurized air cavity 17, which is filled with a certainly pressurized air or nitrogen or helium. On the lower part, the water level fluctuation area forms an airtight shield. Meanwhile, on the top of the core pool (8) there is an airtight shield (12) that forms a secondary air shield. The area between the sealing cover (11) on the top of the core pool (8) and the airtight shield (12) is evacuated to be at a negative pressure to prevent radioactive gases from being released into the environment.

In order to remove the hydrogen and oxygen formed by water decomposition within the sealing cover 11 and the gaseous iodine and radioactive noble gases from fuel fission, the invention includes an air circulation circuit (not shown in the figures) to recombine hydrogen and oxygen as well as to remove iodine and noble gases.

The core is cooled by cooling water flowing out of the core through the support skirt, the lower core grid plate, the fuel assemblies and the upper core grid plate, then flowing into a primary heat exchanger, water pump and the core inlet through the core outlet to form a forced circulation. The heat from primary water is transmitted to an intermediate circuit and then to the third circuit through a secondary heat exchanger. The hot water or steam from the third circuit can be used for heating or desalination.

If this invention is used for isotope production, a target object can be located into the control rod or the irradiation tubes.

Take an example for Qinshan NPP spent fuel assembly pool reactor with normal temperature and pressure (1 bar at the surface of the pool and the average temperature under 100 °C), 121 spent fuel assemblies (the same number as that in the core of Qinshan nuclear power plant) are used, with light water as both coolant and moderator, and thermal power is 200MW. The effective multiplication factor for the neutron chain reaction device is about 1.05, and the heat energy, neutrons and gamma particles produced by the device can be used in relative fields.

(1) If the device is used for heating, it can operate continuously for 600 full power days, supplying fission heat from 121 spent fuel assemblies to an area of 5 million m² for 4 years;

(2) If the device is designed for low-temperature (72°C) water evaporation as a heat supply for low-temperature seawater desalination, it can produce 80,000 tons fresh water (high quality water with 5ppm salt content) daily, continually operate for 600 days at full capacity, and a total of 48 million tones of high quality fresh water can be produced by the 121 spent fuel assemblies.